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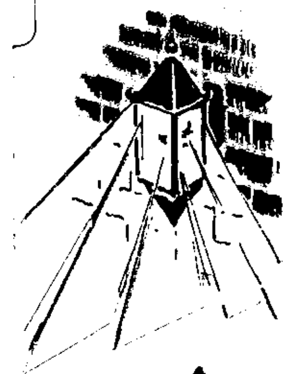
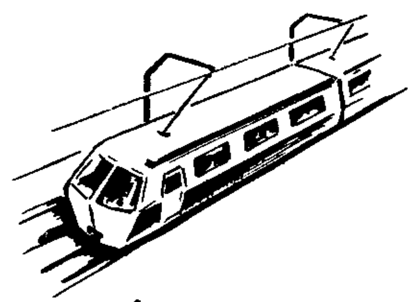


THE IMPACT OF THE MORGANTOWN POWER PLANT ON THE POTOMAC ESTUARY: AN INTERPRETIVE SUMMARY OF THE 1972-1973 INVESTIGATIONS



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December 1975

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Power Plant Siting Program

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THE IMPACT OF THE MORGANTOWN POWER PLANT ON THE POTOMAC ESTUARY: AN INTERPRETIVE SUMMARY OF THE 1972-1973 INVESTIGATIONS

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I. INTRODUCTION

This report summarizes and interprets the findings of aquatic field studies conducted at the Potomac Electric Power Company's Morgantown Steam Electric Station (SES). The purpose of these investigations was to determine if power plant operations would adversely affect the aquatic ecosystem of the Potomac River. The plant is located near the Route 301 bridge, and its once-through cooling system uses tidal-estuarine (mesohaline/oligohaline) waters to remove the waste heat generated in the steam cycle.

Field studies were conducted at the site during 1972 and 1973. These investigations approached the problem of impact assessment by a step-wise process which first ascertained the effects of the plant's cooling system on various biotic components. Subsequently, the river-wide significance of these effects was determined or inferred on the population and ecosystem levels. The investigation of the types and magnitudes of power plant effects under various operating conditions was accomplished by manipulating key cooling-system operating characteristics systematically while measurements were conducted. One of the major types of perturbations investigated was the thermal effect of the plant on aquatic organisms. Seasonal scheduling allowed the measurement of responses to changing ambient thermal conditions. This seasonal scheduling coincided with the natural succession of organisms subject to plant damage.

Determination of power plant effects on various organisms was combined with information on their regional distributions, habitat use patterns, and ecological roles. On this basis, it was possible to arrive at value judgments on the significance of observed plant effects. As a rule of thumb, observed effects on the species level were deemed to have significance, or impact on the ecosystem, only if geographic distributional changes on a scale greater than a tidal excursion distance, or cropping of large fractions of non-renewable organisms, could be inferred. This distinction between effect and impact (i.e., the question of significance) is maintained throughout this report. In many instances, prior knowledge of life history and habitat patterns relative to the plant location allowed judgments on whether the sustainable yield of a resource would or would not be impaired by the plant's operation.

Since power plant impact depends on how a once-through cooling system operates, it is useful to review briefly some of the structures and operational modes associated with it. Power plants with once-through cooling systems, such as the Morgantown SES, draw in large amounts of water (see Section III). The cooling water generally passes through or by several possible intake structures. These structures, which may vary with plant design, include an intake channel, a skimmer (curtain) wall, an intake embayment, and bar screens. The cooling water is further screened by 3/8-in mesh wire screens to keep out debris and larger organisms. Cooling water, possibly treated with biocides, then passes from pumps to the condenser. After the cooling water is heated it passes into the discharge side of the system. During drift through a discharge canal or pipe the effluent may be diluted by tempering pumps using ambient waters. It is finally discharged into the receiving (source) body through a port, or through submerged diffusers.

The stresses an organism experiences on encountering intake, discharge, and condenser structures depend on the mode of its interaction with these plant structures. There are basically three types of interactions aquatic organisms may have with plant cooling systems: entrainment, impingement/entrapment, and nearfield (including plume) residual influence.

Entrainment and nearfield effects were the major concerns of the studies reported here. No impingement/entrapment effects were studied beyond casual observation by research teams on the site.

In entrainment, organisms small enough to pass through the 3/8-in traveling screens located in front of the intake ports will experience rapid thermal rise, pressure changes, turbulence and mechanical abrasion as they pass through the condenser tubes. During biologically productive months, biota in the condensers also may be exposed to high biocide (chlorine) concentrations and to additional abrasion effects from mechanical scrubbing devices (e.g., Amertap). Depending on specific discharge design, thermal and chemical stresses may prevail for hours before ultimate effluent discharge and dilution in the receiving body. Water residence time in the cooling system of Morgantown is approximately 65 minutes.

Total damage by entrainment, caused by combinations of thermal, chemical and mechanical stresses, depends on the number of organisms withdrawn and on the stress doses received in passage through the cooling system. An engineering feature at Morgantown which partially determines the number of organisms entrained is the skimmer or curtain wall in front of the intake embayment. The wall selects the bottom portion of the water column which provides cooler and biologically poorer waters for cooling.

The effects of thermal and chemical stresses on biota may vary depending on the dose received. An operational practice which alters residence times and doses in the system after condenser passage, but before final discharge, is the intermittent use of tempering pumps. These pumps dilute the effluent with ambient (intake) water in the discharge canal in order to meet upper thermal discharge limitations specified in the operating license.

The magnitudes of stresses during entrainment, as well as features and operational practices influencing their severity, were examined quantitatively in these studies. Manipulations of plant operational characteristics during entrainment experiments were sequenced to partition the effects of ambient temperature, thermal rise, dilution (use of tempering pumps), and varying chlorine levels in the cooling system. The organisms subject to entrainment (and to associated stresses) may be grouped into two major categories. The first category includes true planktonic forms, collectively referred to as either holoplankton or euplankton. This group includes microscopic and small (unicellular and multicellular) plants and animals -- the phytoplankton and zooplankton. These forms are largely responsible for primary and secondary productivity in estuarine ecosystems. The second major category of planktonic organisms subject to entrainment consists of early life stages of higher forms (eggs, larvae and juveniles of fish and invertebrate species), of jellyfishes, and of temporary denizens of pelagic habitats, such as bottom-dwelling crustaceans. Whereas the time spent by early life stages and jellyfishes in the water column spans from days to weeks, amphipod crustaceans undergo diurnal-vertical movements off the bottom. These assorted examples of temporary planktonic organisms are referred to collectively as meroplankton. A further distinction is made by making reference to fish eggs and larvae as ichthyoplankton, which, combined with large crustaceans and jellyfishes, constitute the macroplankton. The latter group is sampling-gear specific, and is therefore a useful classification for entrainment work.

The geographic distributions of phytoplankton, zooplankton, bottom-dwelling crustaceans, and jellyfishes are generally broad over estuarine systems. Also, their regenerative capacities (biological compensation for damage from point sources) are high. In contrast, ichthyoplankton are spawned seasonally, and in limited numbers. Furthermore, they are generally distributed over only specific segments of the estuary. Therefore, compensation for entrainment losses is not as likely to occur in these populations.

Nearfield or plume entrainment stresses arise from remnant heat in the receiving body and from chemical residuals which might disperse in significant concentrations over considerable portions of the tidal reach around the site. These stresses may affect planktonic organisms which have or have not passed through the cooling system. Furthermore, fish attracted by physical or biotic changes in the plume region also can be affected. Benthic organisms living in or on the bottom may be directly influenced by water quality in the plume mixing-zone region.

The nearfield studies reported here include estimates of sustained planktonic depletion around the site. The thrust is to ascertain whether organisms damaged in the cooling system account for all nearfield population reductions observed, or if conditions in the vicinity of the discharge may result in further effects, including changes in unentrained portions of planktonic populations.

Finally, impingement on the intake screens and entrapment in the intake embayment are considered only on the basis of vulnerable species present. These species are discussed in terms of their susceptibility to mechanical stress on intake screens, ability to react to intake flow, and susceptibility to other factors, such as "cold shock."

Detailed reports on findings -- Sections V, VI and VII -- are organized according to the sequence of the discussion above. These are preceded by a summary and recommendations section, as well as by site characterization and experimental design descriptions. The recommendations are derived from the findings of this study and extrapolations inferred from biotic and physical characteristics of the entire Potomac estuarine system. Therefore, in addition to evaluations of operational practices and engineering features, the recommendations consider siting options coupled to cooling system design alternatives appropriate for various portions of estuaries.

The study program at Morgantown was supported by the Maryland Environmental Trust Fund, administered through the Power Plant Siting Program (Maryland Department of Natural Resources). The field programs were conducted jointly by the Chesapeake Biological Laboratory of the University of Maryland; the Academy of Natural Sciences of Philadelphia; EPA's National Water Quality Laboratory at Kingston, R.I.; the Water Resources Administration (DNR); and the University of Washington at Seattle. Program integration and evaluations, as well as some field work, were carried out by the Environmental Technology Center of Martin Marietta Corporation.

All participants wish to express their appreciation to the Potomac Electric Power Company for its willingness and cooperation in changing cooling system operating conditions during the studies, as requested by the Program Integrator. Technical direction of the study, and program planning and coordination with PEPCO, were the responsibility of Dr. Leonard Bongers of Martin Marietta Corporation.

II. SUMMARY AND RECOMMENDATIONS

A. Summary of Findings

High zooplankton mortalities (> 50%) have been measured as a result of passage through the Morgantown cooling system only under the most severe thermal and experimentally-applied chlorine stress conditions. For the most part, the same conditions also caused radical reductions in phytoplankton productivity (up to 97%) as measured by C-14 uptake rates. In particular, productivity and levels of live zooplankton abundance were reduced at the outfall, in comparison to the intake, during summer months, primarily when the cooling water was chlorinated. During this period, ambient river temperatures were high, and experimental chlorine concentrations exceeded normal operating levels. At lower ambient temperatures in spring, the experimental chlorine levels still damaged phytoplankton and zooplankton significantly, but thermal doses alone had negligible effects (see Section V). No significant mechanical damage from cooling system passage was detected on phytoplankton and zooplankton.

Of the macroplankton entrained, only ctenophores (jellyfishes) were found to suffer heavy mechanical damage on encountering the screens. No deleterious thermal, chlorine, or mechanical effects were evident on large crustaceans collected in sufficient numbers after cooling system passage.

Studies of phytoplankton productivity in the plant's discharge canal raise questions about the overall ecological value of augmentation (or dilution) pumping. In warmer weather, ambient river water is pumped directly into the effluent canal to help maintain discharge outfall temperatures consistent with State standards. Additionally, however, such pumping involves three further effects: (1) more organisms from the river are exposed to thermal and chlorine stresses in the discharge canal; (2) residence time in the canal decreases; and (3) the plume becomes less buoyant, contributing to recirculation probability of the effluent.

Experimental evidence for questioning the biologically beneficial value of augmentation pumping is limited to the 1972 in-plant studies. Late summer phytoplankton, entrained in the cooling water flow, showed steadily decreasing productivity from intake to discharge outfall, irrespective of augmentation pumping. No differential in productivity was observed in the discharge canal when augmentation and non-augmentation conditions were compared. (That these phytoplankton included recirculated organisms is a possibility.) In the long run, therefore, the practice of augmentation pumping could be biologically counterproductive.

Only the ichthyoplankton of non-commercial species were collected in large enough numbers for qualitative evaluation. For these species the data suggest that thermal, mechanical, and chlorine stresses were all significant in affecting survival.

Reductions occurred in zooplankton population levels and in phytoplankton carbon fixation at the intake as compared to far river locations. Intake carbon fixation was depressed during chlorination conditions with respect to values during periods of no chlorination. Low zooplankton densities were always detected at the intake with respect to river values. For example, carbon fixation at the intake during chlorination periods was consistently less than 50% of the levels observed when no chlorine was injected into the cooling stream. Also, larval stages of zooplankton (nauplii) had consistent intake concentrations which amounted to only 10% to 30% of the densities measured at stations 2 to 2-1/2 mi from the intake.

Intake depletions were found to be in excess of what could be expected (≈23%) on the basis of complete entrainment kill and estimated effluent recirculation rate. This finding indicates that organisms in the receiving body respond to the thermal and chemical properties of the effluent dispersed around the site. Both lethal and sublethal responses to effluent properties have been inferred.

The region of the Potomac River physically and biologically altered by plant circulation, entrainment damage, and effluent properties was found to be small. Changes attributable to plant operation were estimated to extend over only 10% of the river cross-sectional area at the plant site. Estimated linear dimensions of the region within which plant-induced changes could be detected are: 1500 ft extending from the curtain wall to the river channel; and roughly 3000 ft on either side of the discharge. Compared to a tidal excursion distance of 3mi, these dimensions indicate that considerable dilution is occurring.

The rate of water use by the plant is small compared to both tidal and non-tidal transports through the Morgantown cross-section of the river. Based on this and on biological measurements in the river, an entrainment probability of 0.02 has been estimated for planktonic organisms. Thus, under the most stressful conditions (total entrainment mortality), only 2% of the plankton transported past the plant in the river cross-section would be destroyed by entrainment. The significance of additional observed nearfield effects is poorly understood, but is thought to be minor at least for zooplankton, as discussed in Section VI.

Since most of the planktonic forms are distributed over a broad segment of the river and also have high reproductive rates, no significance (adverse impact) can be assigned to the observed plant damage. Only ichthyoplankton lack the regenerative capacity to compensate for destruction by plant operation.

Since anadromous spawning and nursery grounds are generally located 15 to 20 mi upstream of the site, it is expected that most of the entrained ichthyoplankton would be eggs and larvae of ubiquitous estuarine species. As discussed previously, the majority of ichthyoplankton collected in the entrainment studies were those of non-commercial ubiquitous species. Therefore, the Morgantown plant would not impact the sustained commercial yields of fish populations in the Potomac by entrainment of their eggs and larvae.

Moreover, the plant is located near the Potomac's saltwater-brackish water interface where the levels of many aquatic populations taper off. This biological zonation applies to species in all trophic levels in the Potomac ecosystem, including juvenile and adult forms susceptible to impingement and plume effects. Appreciable harvesting of the most important resources occurs upstream or downstream of Morgantown. The location of the plant and the relatively small and local changes which the plant produces in the surrounding aquatic environment indicate that the Potomac River ecosystem is not impacted by the operation of the Morgantown Steam Electric Station.

B. Recommendations on Siting, Design, and Operational Strategies to Minimize Power Plant Impacts

The following recommendations represent insights, conclusions and extrapolations derived from the impact assessment of the Morgantown SES. The selection and implementation of options should be based on field measurements at specific sites and on knowledge of regional distribution characteristics of biotic resources.

1. Site Selection

In general, environmental impact can best be minimized through proper site selection. The location of a site should be selected in a regional context favorable to the maintenance of the ecosystem in terms of sustained yield resource exploitation and ecological integrity.

In the Potomac, we find that the saltwedge transition zone (salinity range from about 3 to 10 ppt) is particularly suitable for siting a large power plant. Although commercial exploitation of adult fish stocks is distributed over most of the tidal portion of the estuary, the early life-history stages liable to entrainment are distributed well upstream of this zone. Whereas most true planktonic species are present over extensive segments of the estuary, and throughout the annual cycle, anadromous fish spawning is relatively specific in duration and location, and so is the distribution of early life stages. In the same vein, most of the exploitation and propagation of benthic resources (oysters, clams, and crabs) occurs downstream of the salinity transition zone. As discussed in Section VII, salinity preferences of major biological distributions are characterized by three salinity regions. The saltwedge transition zone is near the dynamic boundary between the unidirectional river flow and the two-layered gravitational circulation in the estuary.

In smaller estuarine systems, the salinity transition zone will not be automatically suitable for power plant siting. If migratory activity is restricted to narrow channels, and if relatively extensive modifications (thermal, chlorine residuals, and trace metals) can be induced laterally and transported longitudinally, the size of the system must be critically weighed against generating capacity and cooling system configuration.

Generally, siting and once-through cooling are favored in salinity transition zones of large systems with high flushing rates. Dynamic limitations and anadromous spawning sites in fresh and low-brackish tidal portions favor smaller generating capacities and cooling tower use. Although vertical salinity stratification in high salinity regions allows several configuration options and generating capacities consistent with the size of the system, the selected mode for cooling is dependent on the specific biotic component to be protected. A qualitative scheme for considering realistic strategies for the protection of biotic components of interest is presented below. The criteria by which these options have been constructed for various estuarine regimes are largely outgrowths of the Morgantown SES impact assessment. The options represent syntheses of projected interactions among the physical and biological dynamics affected by plant-induced environmental modifications. These projections depend on the biological zonation associated with salinity change in the estuary.

2. Cooling System Design

Cooling system design criteria include fixed features that control temperature rise across the condensers and in the nearfield, biocide use, and the dispersion of biocide residuals. The structures and facilities controlling thermal and chemical effects include intake and outfall configurations, augmentation or tempering pumps, discharge canals, submerged ports or diffusers, cooling towers, and holding ponds. Cooling ponds are not considered in this discussion.

Because effects either similar to or greater in magnitude than those found in cooling system passage were detected in the nearfield of the plant, design criteria must also be directed to minimization of effects in the mixing zone. The specific design determines the interaction between river dynamics and discharged water in density-stratified systems. Consequently, mixing of thermal and chemical discharges may be enhanced by utilizing properties of river dynamics; or, alternatively, the size of the mixing zone may be delimited to confine regions of nearfield impact either longitudinally, laterally, or vertically in the water column. Concomitant build-up of plant effects close to the site due to the selection of the latter class of options may be desirable to localize decay of heat and toxic by-products of biocide addition. Obviously, the use of this class of options is highly restricted by the homogeneous character of flows and lack of water column stratification in fresher portions of the estuary.

Table II-1 presents several cooling system design options available for various qualitatively described portions of the Potomac estuary. Each column in the table represents design strategy composed of a number of preferred or undesired cooling system features, together with physical and associated biological consequences of design implementation. The options described below under (a), (b), and (c) are shown in Table II-1, from left to right. At the present time, it is not possible to define the desired generating capacity or the adequate flushing flow for a given power rating quantitatively.

a. Options for High Salinity Regions

In wide, stratified portions of the estuary, with high salinity and vigorous tidal and non-tidal flushing, it is desirable to disperse

TABLE II-1

Guidelines for Cooling System Design in Tidal Estuaries

	High Salinity				Salinity Transition				Brackish-Fresh		
	Options (a)				Options (b)				Options (c)		
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Cross-Sectional Area		H		L		H		L		H	L
Flushing	H	H	H	L	H	H	L	L	H	L	L
Cooling Mode	OT	OT	OT	CT	OT	OT	OT	CT	OT	CT	CT
Generating Capacity	H	H	H	L	H	H	H	L	L	H	L
Deep Intake and Embayment	+	+	-	-	+	+	+	-	-	-	-
Full Depth or Surface Intake	-	-	+	+	-	-	-	+	+	+	+
Condenser Thermal Rise-ΔTc	H	H	H	H	L	H	H	H	H	H	H
Condenser Volume Flow-Qp	L	L	L	L	H	L	L	L	L	L	L
Augmentation Flow	(+)	-	-	-	(+)	-	-	-	(+)	-	-
Discharge Canal	+	-	-	-	+	+	-	-	-	-	-
Discharge Location	DS	MC	MC	MC	US	DS	MC	MC	MC	MC	MC
Surface Momentum Jet	+	-	-	-	+	+	-	-	-	-	-
Bottom Diffusers or Jet	-	+	+	+	-	-	+	+	+	+	+
Biocide Requirement	H	H	H	F	F	L	L	F	L	L	F
Mechanical Antifouling Req.	+	+	+	-	+	+	+	-	-	-	-
Chlorine Alternative Desired	+	+	+	-	+	+	+	-	-	-	-
Recirculation Probability	L	F	L	L	H	L	L	L	L	L	F
Dispersal	F	H	H	H	L	L	H	H	H	H	H
Well-Defined Mixing Zone	Yes	No	No	No	Yes	Yes	No	No	No	No	No
Option Specific to:											
Ichthyoplankton protection	x	x		x		x	x	x			
Plankton protection	x			x	x		x	x		x	
Juvenile and adult fish			x	x				x			
Migratory access	x			x	x	x		x	x	x	x
Benthic resource protection		x	x						x		

L = Low
H = High or Large
F = Fair

+ = Required or desirable
- = Rejected
(+) = Desired during chlorination

OT = Once-through cooling
CT = Cooling tower
X = Applicable

US = Upstream from intake
MC= Mid-channel bottom
DS = Downstream from intake

and weaken the area of environmental modification induced by the plant. Geometrically, such a practice would not interfere with migrations, and most effects will be diluted by size alone.

(1) Withdrawal from the bottom layer with a once-through cooling system may involve intake embayment and curtain wall use, which may pose impingement and/or entrapment problems for finfish. In order to achieve a low volume flow, a relatively high thermal rise will result, but heat will be dispersed rapidly by natural processes. Discharge plumes will be buoyant and will disperse in the surface layer, being flushed downstream of the site. It is, therefore, desirable to use a discharge canal with outfall downstream of the intake to take advantage of the slight longitudinal gradient in surface density. The latter feature enhances buoyancy and surface dispersion. Augmentation would have a tendency to make the discharge less buoyant; however, it may be used to dilute biocide residuals. Biocide requirements increase with salinity, but the relatively low condenser volume flow will reduce total biocide input. This design results in low recirculation probability due to a floating plume and deep intake; the design provides for low impact on plankton, but may be adverse in terms of fish impingement and entrapment. Subtidal benthic communities may be affected by the near-shore discharge mode. If augmentation is to be used, it should be injected at the end of the discharge canal to minimize exposure of organisms that have not passed through the cooling system.

    Because biofouling can be severe in this region and chlorine demand is usually high, a mechanical antifouling system should be used to reduce the chlorine requirement. A more rapid dissipation of chlorine residuals may be achieved by the input of augmentation water at the end of the discharge canal.

(2) The second option in high salinity regimes is similar to the first in intake characteristics. Discharge dispersal is achieved through submerged jets or diffusers located in the high transport, mid-channel region. No augmentation or discharge canal is necessary.

    A combination of a mechanical antifouling system and intermittent biocide use, alternated among units, should be employed to reduce the level of biocide residuals at the point of discharge. This design is a specific option for the protection of subtidal benthic communities, such as oyster bars and clam beds. Mid-channel dispersal of the effluent carries away biocide residuals and leached heavy metals. These estuarine areas are dominated by true estuarine and marine species having extensive distributions, and no impact on plankton is expected. Shellfish resources with pelagic larval stages could be adversely affected if their distribution is restricted to the site. The possibilities for impingement of finfish and juvenile crabs still exist, but the large dispersion of the thermal plume provides less of a stimulus for fish congregations in the outfall or intake areas.

(3) The combination of full depth or surface withdrawal and mid-channel diffusion in high salinity regions serves to protect finfish and benthos from intake and plume effects, respectively. However, planktonic forms may be adversely affected by entrainment damage because, on the average, more planktonic biomass would be drawn into the cooling system. The restrictive biocide use discussed above also applies to this configuration. Care must be exercised to avoid this mode if large numbers of pelagic larvae of important species are present in the area.

(4) In smaller estuaries, with sluggish flushing and small cross-sectional area, cooling tower use is a preferred option in combination with lower generating capacities. Shallow, full depth withdrawal seems most suitable for make-up water intake. This design avoids entrapment problems for finfish. Bottom diffusers allow maximum dispersion and prevent thermal blocks from forming across the estuary. Holding ponds should be utilized for treatment of chemically loaded blowdown, including high biocide residual concentrations resulting from the high salinity location. The dispersion of chemical pollutants would have the most pronounced effects on benthic organisms, with relatively minor impact on other biotic components.

b. Options for Salinity Transition Regions

In salinity transition regions of large estuaries, important biotic distributions taper off from those both up- and downstream. Viable options exist both for confining plumes to surface layers along the shore and for longitudinal confinement by creating vertical convection of the discharge with high recirculation probability. Alternatively, high dispersion may also be achieved. These options are all consequences of the utilization of stratified estuarine dynamics to achieve desired mixing zone dimensions by adjustment of intake source regions, volume flow, temperature rise, and discharge configuration.

(1) The first design option (implemented at the Morgantown SES) produces vertical convection of the thermal effluent by virtue of low condenser thermal rise, deep water intake, and surface discharge. The effluent is not warm enough to remain buoyant, and a large fraction sinks back to the intake depth. Because of tidal oscillations, the sinking plume has a relatively large probability of remaining in the intake area, with an associated build-up of chlorine residuals and heat near the plant intake. These induced changes could lead to avoidance of the nearfield

by ichthyoplankton and zooplankton. Or, the nearfield thermal and chlorine stresses could act synergistically, resulting in nearfield depletion through mortality, which would add to entrainment kills. Augmentation pumping or intermittent chlorination should be applied to diminish the nearfield chlorine residual effects. Alternative biocides, such as ozone and bromine chloride, appear preferable to chlorine. From a biological point of view, augmentation is not advantageous because stressed, unentrained organisms from the nearfield, in which a sustained thermal and chemical build-up is encountered, are subjected to further stress in the discharge canal. The sinking plume might affect occasional oyster bars in the vicinity of the site, and also other components of the benthic community. The upstream location of the discharge from the intake enhances plume sinking and recirculation, especially on ebb phases of the tide. The reason for this behavior is the existence of relatively sharp longitudinal gradients in density and density differences between the effluent and receiving waters created by opposite flows in the river and discharge canal on the ebb tide.

(2) Maintaining the deep water intake and radically increasing the condenser temperature rise would result in consistently buoyant plumes and lower water use. To facilitate surface dissipation, the discharge site should be placed downstream of the intake. Discharge canal flow and river flow would now be out of phase on the flood tide, enhancing buoyancy of the surface plume and downstream flushing by nontidal advective flows. Nearfield buildup of heat would be shifted downstream of the intake, and recirculation probability would be reduced. Lateral shear in the river channel would tend to restrict the surface thermal rise to regions along the bank of the river. Improvements would be achieved in both planktonic and benthic protection. The low condenser volume flow would drastically reduce chlorine need, and the higher temperature rise would make the added chlorine more effective. Intermittent chlorination, alternating among units, should be applied.

(3) High dispersal of the thermal effluent may be required in wide systems with sluggish flushing characteristics. This dispersal can be achieved with the use of bottom diffusers. Migratory access to areas upstream of the site might be affected by reactions of finfish to dispersal of the thermal load mid-channel. Because of high water residence time near the site, planktonic organisms will have a high probability of entrainment and mortality. With low flushing, the entire cross-section of the estuary could be affected. The same fouling prevention recommended for the immediately preceeding option applies here.

(4) The salinity transition zone in small systems suggests lower generating capacities and cooling tower use. Surface or full-depth intake structures are recommended to reduce potential impingement and entrapment of finfish. Low water use, high

condenser thermal rise, and bottom diffuser outfalls mid-channel seem to be the design combination producing minimal effects. The most serious concerns with this siting and operational option are a possible establishment of a thermal block in a narrow water body and accumulation of blowdown and biocide chemicals affecting the benthos.

c. Options for Fresh and Brackish Regions

Fresh and low-brackish waters present a limitation on options, confining the plume in a particular portion of the water column. The protection of ichthyoplankton is a major concern at these sites. The less water utilized, the more advantageous the particular option in these locations.

(1) In wide systems with large tidal influence in the freshwater segment, once-through cooling may be acceptable. Low-volume plant cooling flows would imply high thermal rise and low generating capacity, together with mid-channel diffusers to provide for dispersion. Since thermal and biotic vertical stratifications are weaker, a full depth or surface intake may be advantageous to circumvent impingement and entrapment problems with finfish. Since chlorine demand is relatively low in fresh waters, chlorine input is low, and nearfield effects of residual concentrations are of little concern.

(2) High generating capacities would require the use of cooling towers in this portion of the river. With the exception of augmentation, all other features would remain the same as in the previous option. Retention ponds for blowdown chemicals are desirable in fish spawning and nursery areas.

(3) For fresh and low-brackish portions of small systems, with perhaps weak or no tidal influence, cooling tower use may be considered a requirement. Capacity also must also be curtailed. Mid-channel diffuser use with all cooling tower configurations is desirable.

The preceding options would apply to the future siting, design, and operation of power plants on estuaries. Options requiring modifications for backfitting at existing facilities have not been identified. Cumulative effects from other pollutant sources also must be considered in selecting particular options.

III. SITE AND PLANT CHARACTERISTICS OF THE MORGANTOWN STEAM ELECTRIC STATION

A. Location and River Characteristics Near the Site

PEPCO's Morgantown Steam Electric Station (SES) is located on the Potomac River in Charles County, Md. The site is approximately equidistant from Washington, D.C. and the confluence of the river with Chesapeake Bay. At this point (near the Rt. 301 bridge), the river estuarine, with a mean cross-sectional area of $19.1 \times 10^3 m^3$ ($205.0 \times 10^3 ft^2$). Average water depth is about 7 m (23 ft). (See Fig. III-1.)

The flow regime is typical of a partially mixed estuary subject to moderately strong tidal currents. Distinct non-tidal flows are developed, directed downstream in the surface layers and upstream at depth. The difference in volume transports between the two layers is the accumulated freshwater input from upstream of the site. Freshwater flow past the plant ranges typically between 140-to 1400 m^3/sec (5000 to 50,000 cfs). The more apparent, oscillating tidal flows transport between 10 and 20 times the freshwater volume transport on the average (root mean square). Mean peak tidal velocities are approximately 0.5 m/sec (1.4 fps) in the river.

B. Cooling Water Flow

A once-through cooling system is employed at the plant to reject the waste heat of the twin 570-MWe generating units. Separate condenser systems cool each unit. The condenser discharge from both condensers enters a long discharge canal which returns the thermally elevated cooling water into the river through a momentum jet located 0.5 km (0.3 mi) upstream of the intake.

Cooling water is drawn from the river through a deep-water intake structure. Lower layer withdrawal is accomplished by a combination of a curtain wall reaching 10 m (33 ft) below the mean low water level and an intake channel dredged to 15.2 m (50 ft), extending from the river channel to the curtain wall. The intake channel is 520 m (1700 ft) long and 106 m (350 ft) wide (Fig. III-2).

Since temperature and salinity vary continuously through the annual cycle, the vertical density structure of river water determines the strength of selectivity in deep water withdrawal. As long as relatively small (0.1 ppt) salinity differences exist vertically, the curtain wall is effective in drawing water from layers 10 m (33 ft) below the surface (Obremski, 1975). This situation prevails during most of the year. Because there are longitudinal temperature and salinity gradients in the river that vary tidally, the depth of flow separation near the curtain wall may also change with a tidal period.

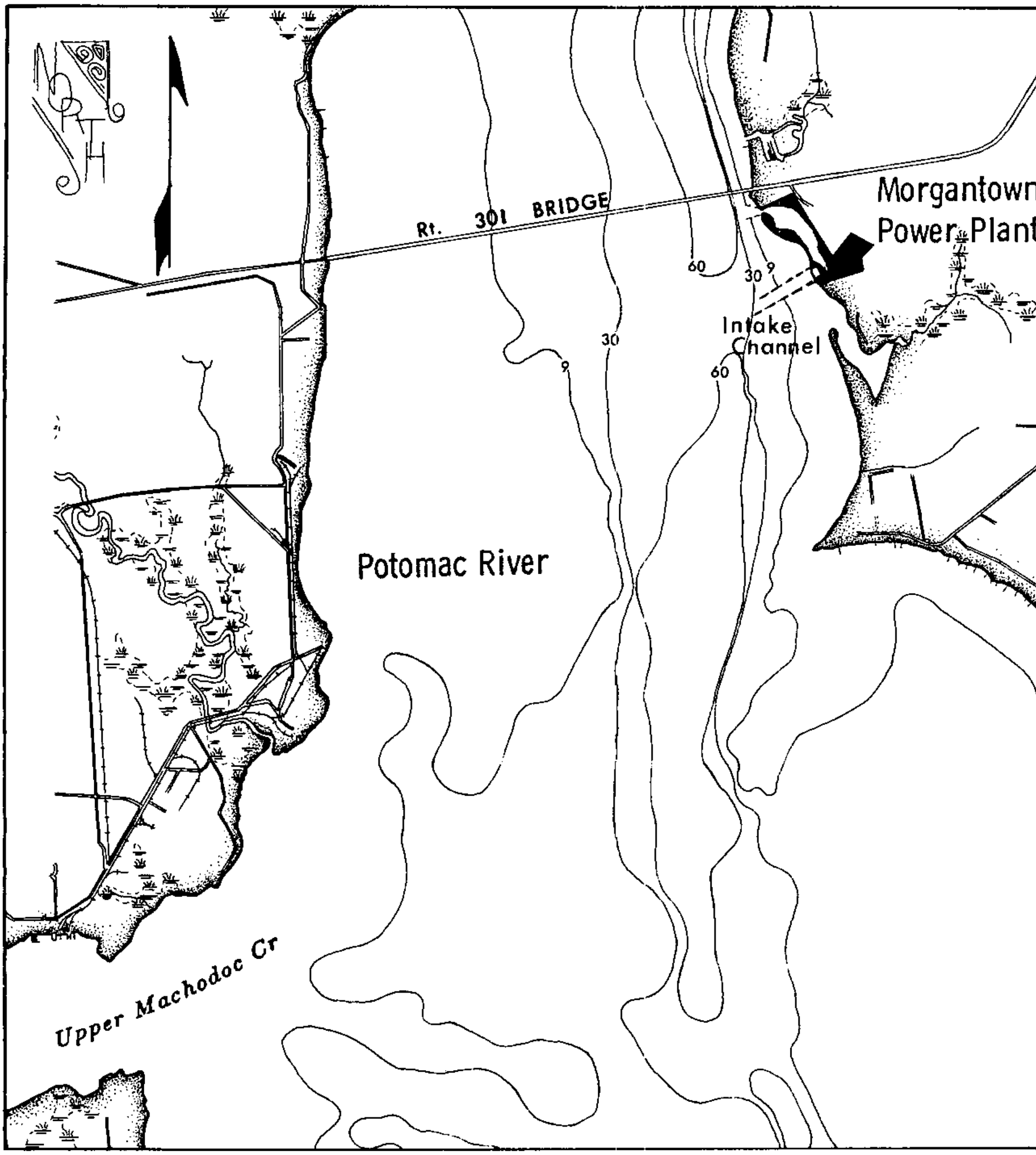

Fig. III-1. Map of Potomac River in the vicinity of the Morgantown Steam Electric Station.

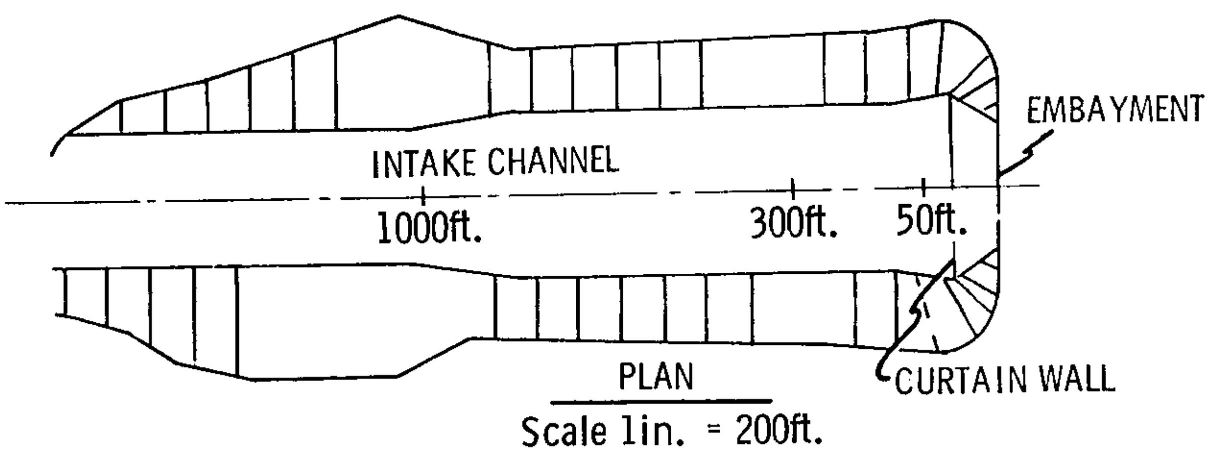

Fig. III-2. Plan view of intake channel, curtain wall, and intake embayment.

The selective deep-water withdrawal action of the curtain wall has been demonstrated by intake velocity profile measurements (Obremski, 1975). Flow patterns induced by the circulating pumps and constrained by the baffling action of the curtain wall show velocity vectors near the curtain wall to be directed toward the plant near the bottom of the intake channel (Fig. III-3). The pumping influence of the cooling system can be detected from several hundred to as much as a thousand feet from the curtain wall, depending on tidal phase.

The cooling water drawn in underneath the curtain wall at average velocities of 0.09 to 0.15 m/sec (0.3 to 0.5 fps) is mixed rapidly in an intake embayment before entering the intake ports located behind the bar and traveling screens. The intake embayment has a volume of $25 \times 10^3 m^3$ ($90.0 \times 10^4 ft^3$) which, together with the pumping rate, results in residence times of between 4 and 7 minutes in the embayment (Table III-1).

The pumphouse, which is also the site of chlorine injection into the cooling stream, is located behind the trashracks and vertical traveling screens. There are two sets of three pumps, one set per generating unit. To temper the water in the discharge canal during warmer months, the cooling system of each unit is equipped with a tempering or augmentation pump. The augmentation flows bypass the condenser system and are diverted into the discharge canal at the points where the condenser outflows are located.

Table III-2 shows the various volume flow rates for each unit, with and without augmentation pumping. The effects of augmentation or single unit operation, and of combinations of these conditions, are observable through variations in water residence time across the entire cooling system (Table III-2) and also in variations of the intake velocities.

The depth of the discharge port is 6.1 m (20 ft), and the width is adjustable up to about 4.6 m (15 ft). The river depth at the point of discharge is about 6.1 m (20 ft) as well. At a cooling water flow rate of 62 m^3/sec (2200 cfs) (two units operating) the width of the discharge is adjusted to about 10 ft, thus maintaining an exit velocity of about 11 fps.

Knowledge of variations in water residence times (in the cooling system) is necessary for proper phasing of biological sampling at various points in the system. Maintenance of the sample phasing sequence is crucial to mortality data collection since entrained planktonic distributions tend to be patchy.

As evidenced by an absence of noticeable fish-kill episodes, most estuarine species encountering the intake structures are able to avoid entrapment and impingement. Intake velocities of less than 0.5 fps may be overcome by fish greater than 5 cm in length, assuming a sustained cruising speed of three times the body length. During winter, when intake flow rates are consistent at the lowest levels, pump-induced velocities would pose no danger to smaller fish.

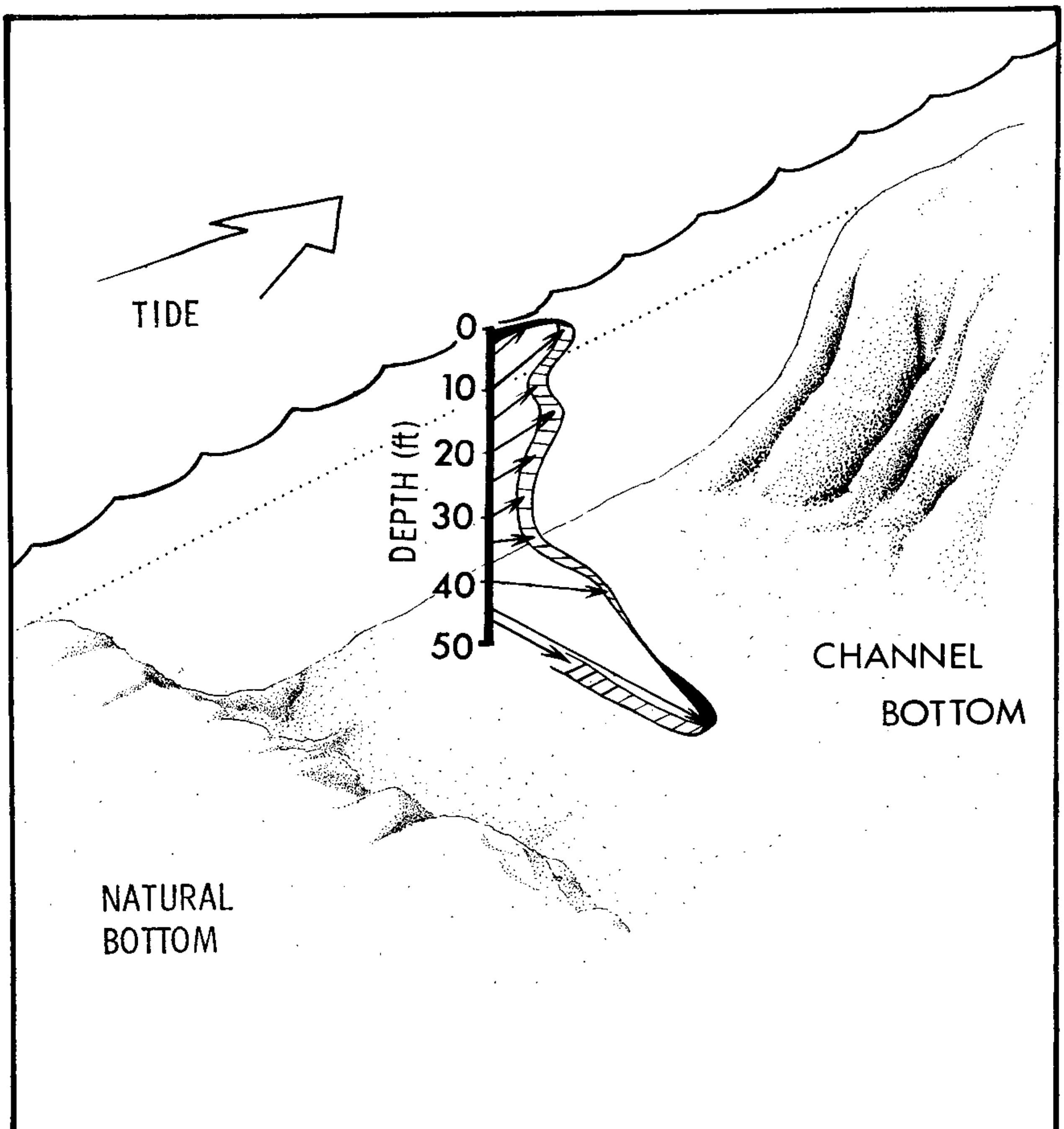

Fig. III-3. Schematic representation of typical flow patterns in the intake channel measured 500 ft from the curtain wall during flood phase. Arrows indicate the direction of flow, showing river axial flow direction at the surface and transverse flows in bottom layers.

TABLE III-1

Average Transit Times through the Morgantown Cooling System

	Water Use			
	2200 cfs (no augmentation)		3600 cfs (with augmentation)	
	Δ Time (min)	Σ Time (min)	Δ Time (min)	Σ Time (min)
Curtain wall to circulating pumps	7	7	4	4
Circulating pumps to discharge channel	2	9	2	6
Head discharge channel to outfall	66	75	40	46
Outfall to river ambient*	2	77	2	48

* Cooling water is assumed to be of ambient conditions when reduced half of the temperature rise.

TABLE III-2

Morgantown SES Cooling Water Flow Characteristics

Parameter	Metric Unit	Engineering English Units	Remarks
Condenser Flow			
1 unit	31.2 m^3/sec	1100 cfs	130-min residence time
2 units	62.4 " "	2200 "	65-min residence time
Augmentation Flow			
1 unit	19.9 m^3/sec	700 cfs	Augmentation is used
2 units	39.8 " "	1400 "	during summer months.
Max. Flows	172.2 m^3/sec	3600 cfs	Total residence time is 40 min.
Intake Velocity (Winter)	0.10m/sec	0.32 ft/sec	No augmentation flow (Nov. through May)
Intake Velocity (Summer)	0.16m/sec	0.52 ft/sec	With augmentation flow (June through Oct.)
Discharge Velocity	3 m/sec	9.8 ft/sec	Adjustable
Temperature	5 to 6.1 C	9 to 11 F	At full load
Chorination	500 kg/day/unit	1100 lb/day/unit	Typical (June through Nov.)
	450 to 1350 kg/day/unit	1000 to 3000 lb/day/unit	Normal range (" ")
	2700 to 3600 kg/day/unit	6000 to 8000 lb/day/unit	Experimental inputs
Cl_2-concentration			
at 900 kg	0.16 mg/liter		At point of injection
2700 kg	0.50 mg/liter		"
3600 kg	0.67 mg/liter		"

C. Entrainment Stresses Within the Cooling System

At full load, the heat absorbed by the cooling water amounts to 1.6×10^{11} BTU per day. During passage through the condenser system, an abrupt rise in water temperature occurs, amounting to about 10 F (5.6 C).* Temperature decay through the cooling system is slow, amounting to less than 10% of the 10 F rise across the condensers. The phytoplankton, nannoplankton, fish eggs and larvae, and other small organisms present in the cooling system will experience a thermal dose of 650 F degree-min when no augmentation is applied, assuming a 65-min transit time and a 10 F temperature rise. With augmentation flow, the thermal dose experienced is less, due to a decreased exposure time and dilution of condenser discharge with tempering water. Temperature elevations are reduced to approximately 6.5 F at the end of the discharge canal. In the latter case the thermal dose is 260 F degree-min.

In addition to thermal stresses, biota entrained in the Morgantown SES may be affected by mechanical stresses caused by abrasion, velocity shear, and rapid pressure changes. Lauer et al. (1974) estimated that organisms entrained in the Indian Point SES experienced a minimum pressure of 4.3 psi and a maximum pressure of 23.6 psi during passage. Although the effects of these mechanical stresses have not been quantitatively determined, it appears from our investigations at Morgantown that the effects of mechanical damage are insignificant compared to the effects of chlorine and thermal stresses.

During warm months, a mechanical antifouling system (Amertap) is used in conjunction with continuous low-level chlorination (1000 to 3000 lbs/ day/ unit) to prevent biofouling of condenser tubes and intake conduits. The chlorine, introduced as hypochloric acid, is injected into the cooling water immediately behind the traveling screens. During 1972 and 1973 entrainment studies, chlorine levels of up to 6000 lb/ unit/ day were applied on an experimental basis to aid in evaluating biotoxicity and environmental effects. Chlorine is the principal agent used in power plants for biofouling prevention due to its effectiveness at relatively low concentrations, as well as its quick dissipation. The Morgantown SES uses about 0.5×10^6 lbs per year. The estimated total annual usage of chlorine in Maryland in power plant cooling systems and in the chlorination of sewage combined is about 25×10^6 lbs.

There is concern about the fate of chlorine reaction products and their impact on the aquatic environment. Principal chlorine species which are produced by the introduction of gaseous Cl_2 into water are hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-). These two species, referred to as free available chlorine, might combine with organic constituents present in the cooling water to form combined available chlorines such as the mono-, di-, and trichloramines. These

*Temperatures in this Section are expressed in $^{\circ}$F for ready comparison with State standards.

products are less effective as antifouling agents, but because of slower decay rates, they are present within tidal excursion distance of the plant for a relatively long period, as implied by the dye studies of Carter (1973). Mortality, depressed activity, and avoidance have been reported at residual levels of chlorination by-products as low as a few ppb (e.g., Brungs, 1973).

Chlorine is used in the Morgantown SES cooling system for approximately six months per year (June through November). To provide a basis for calculations of toxicity to entrained biota, the decay rates of free available chlorine and the combined available chlorine were determined in 1973 between the point of injection and outfall. The concentrations of free chlorine and total chlorine observed during a 24-hr sampling period at S4 (the point at which the condenser effluent enters the discharge canal) and at S5 (outfall) are illustrated in Fig. III-4. The observed values varied dramatically with time of day and sampling location, even though input rates were maintained at a constant level. Apparently, the "chlorine demand" of the cooling water -- i.e., the content of constituents which can be oxidized by the chlorine species -- is variable with time. Although inputs of chlorine were relatively high during the experimental periods, there was sufficient time for most of the free and combined chlorines to dissipate during passage in the discharge canal.

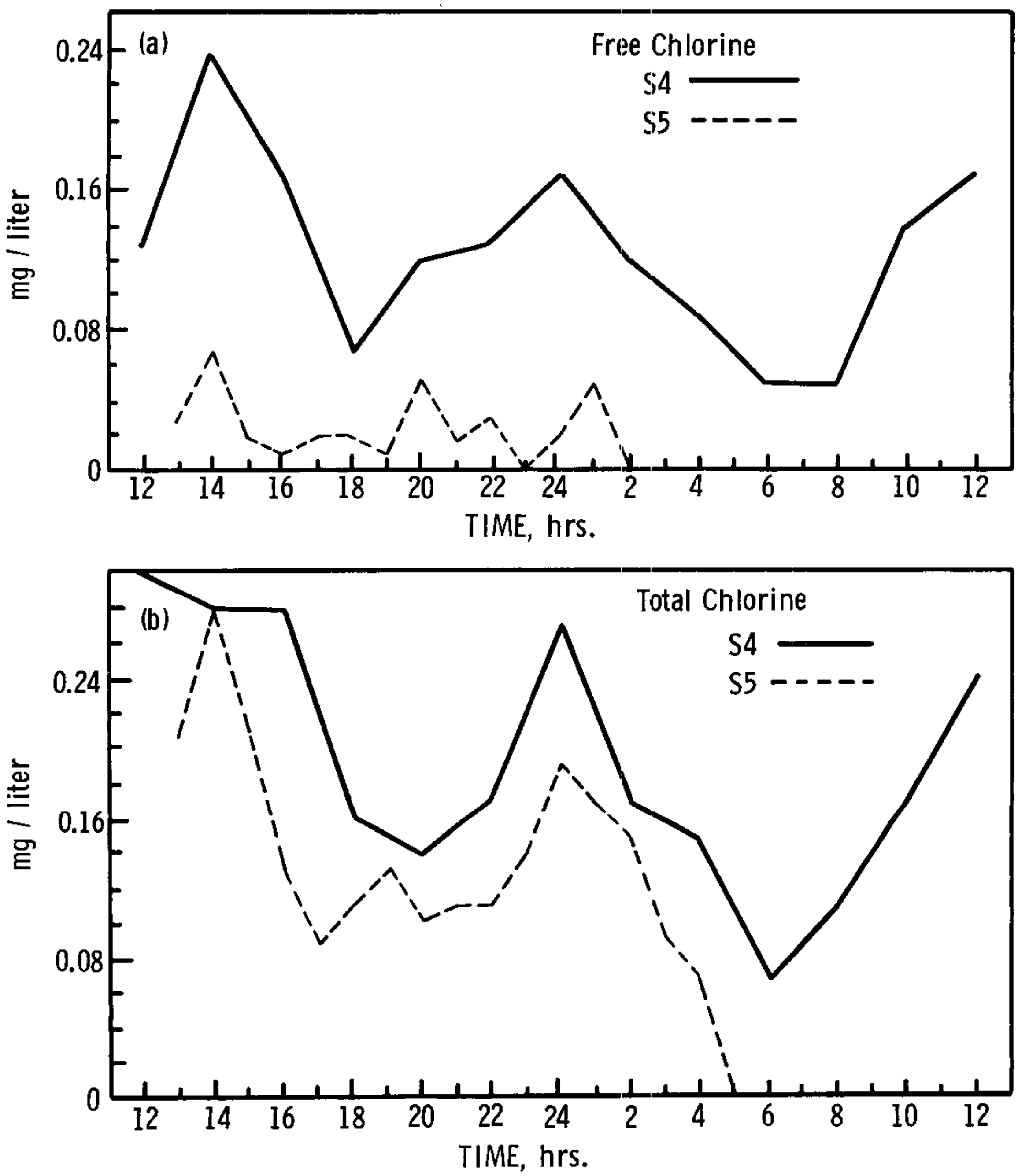

Fig. III-4. Concentrations of (a) free chlorine and (b) total chlorine in cooling water at sampling stations S4 (condenser discharge) and S5 (outfall) over a 24-hr period. Chlorine input was constant at 6000 lb/day/unit. The free chlorine concentration at point of injection was calculated at 0.5 ppm.